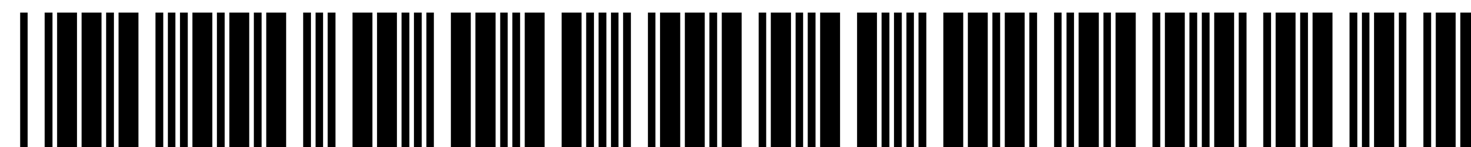
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(45) Date of Patent: Sep. 28, 2004

(54) **PROCESS FOR MAKING A HEATER CHIP MODULE**

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(73) Assignee: **Lexmark International, Inc.**, Lexington, KY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/166,273**

(22) Filed: **Jun. 10, 2002**

(65) **Prior Publication Data**

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Related U.S. Application Data

(62) Division of application No. 09/099,854, filed on Jun. 19, 1998, now Pat. No. 6,449,831.

(51) **Int. Cl.**[7] **H05B 3/00**

(52) **U.S. Cl.** **29/611**; 29/890.1; 29/889.22; 347/47; 347/56; 347/65; 216/27; 216/33

(58) **Field of Search** 347/17, 58, 63, 347/50, 56, 65; 216/33, 27, 16, 48; 29/611, 890.1, 889.22

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Primary Examiner—Minh Trinh
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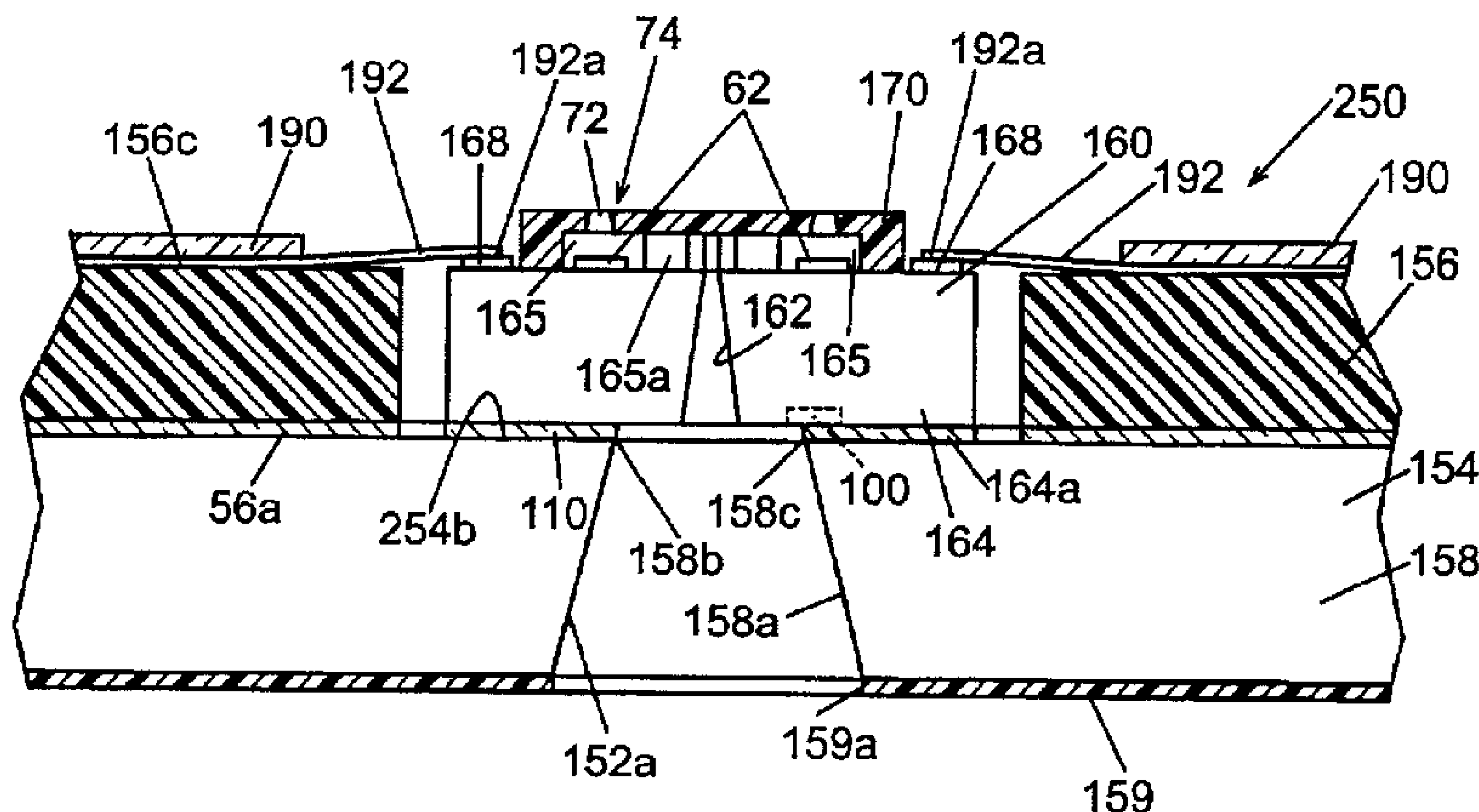
(57) **ABSTRACT**

A process is provided for forming a heater chip module comprising a carrier adapted to be secured to an ink-filled container, at least one heater chip having a base coupled to the carrier, and at least one nozzle plate coupled to the heater chip. The carrier includes a support substrate having at least one passage which defines a path for ink to travel from the container to the heater chip. The heater chip is secured at its base to a portion of the support substrate. At least the portion of the support substrate is formed from a material having substantially the same coefficient of thermal expansion as the heater chip base. A flexible circuit is coupled to the heater chip module such as by TAB bonding or wire bonding.

10 Claims, 7 Drawing Sheets



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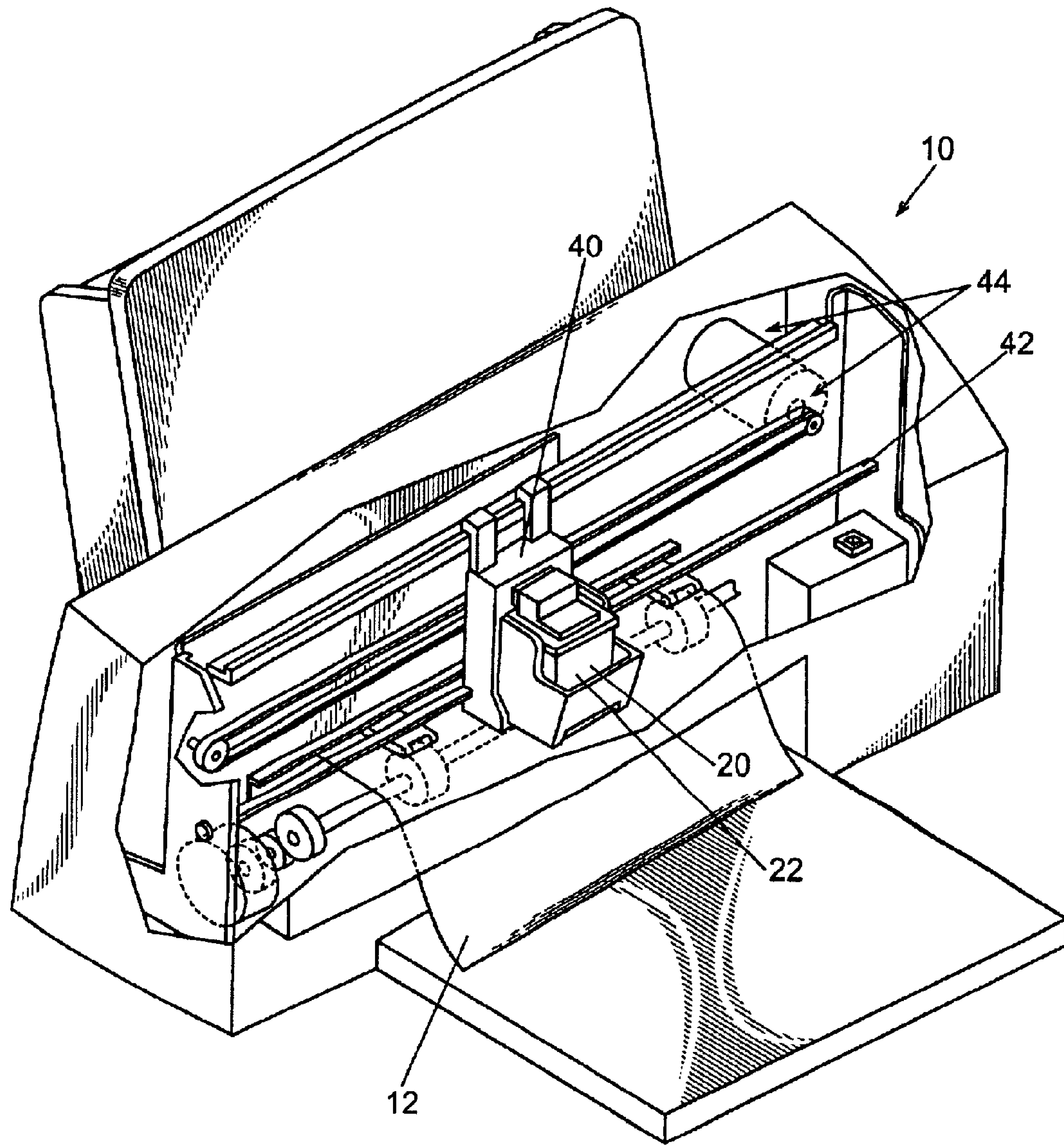


Fig. 1

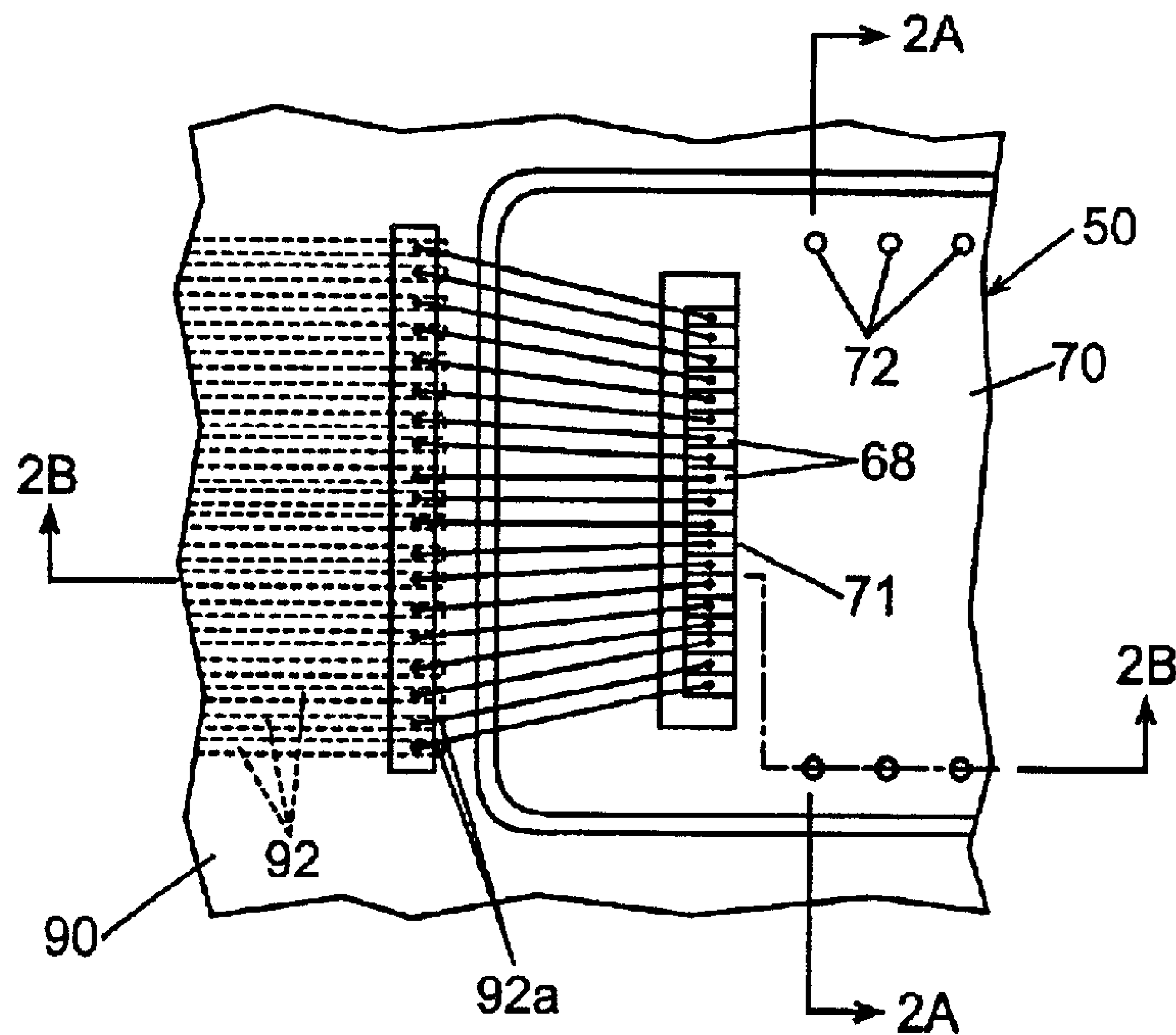


Fig. 2

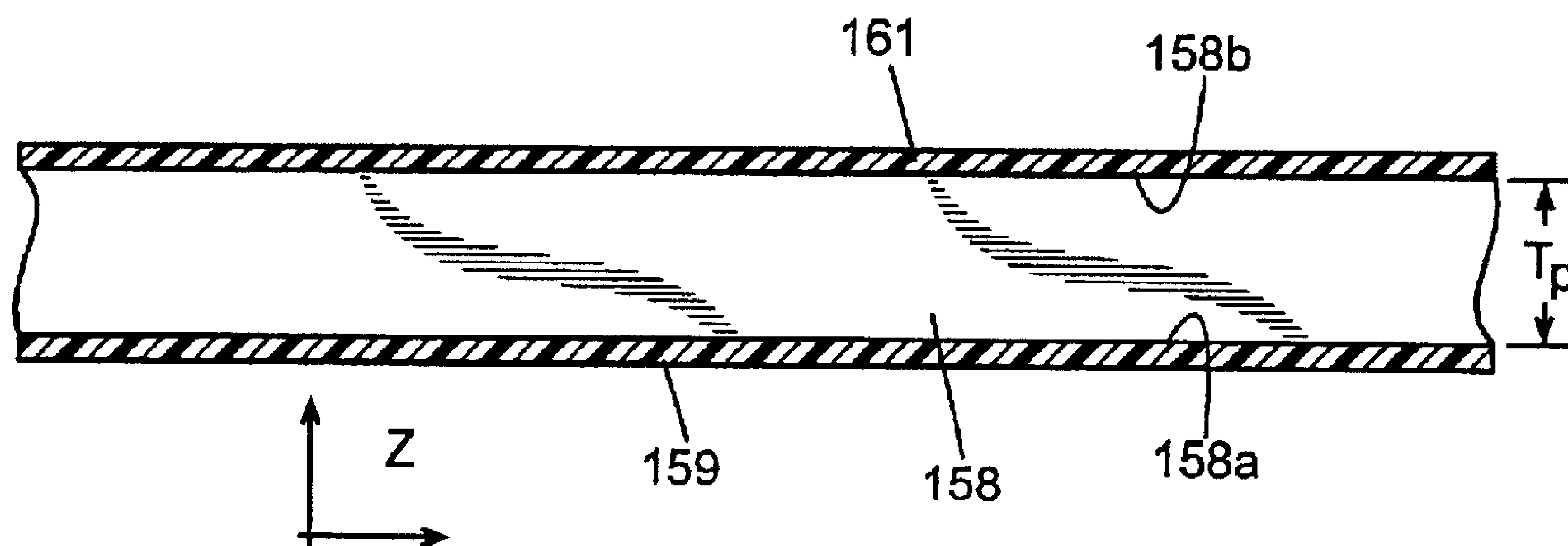


Fig. 3

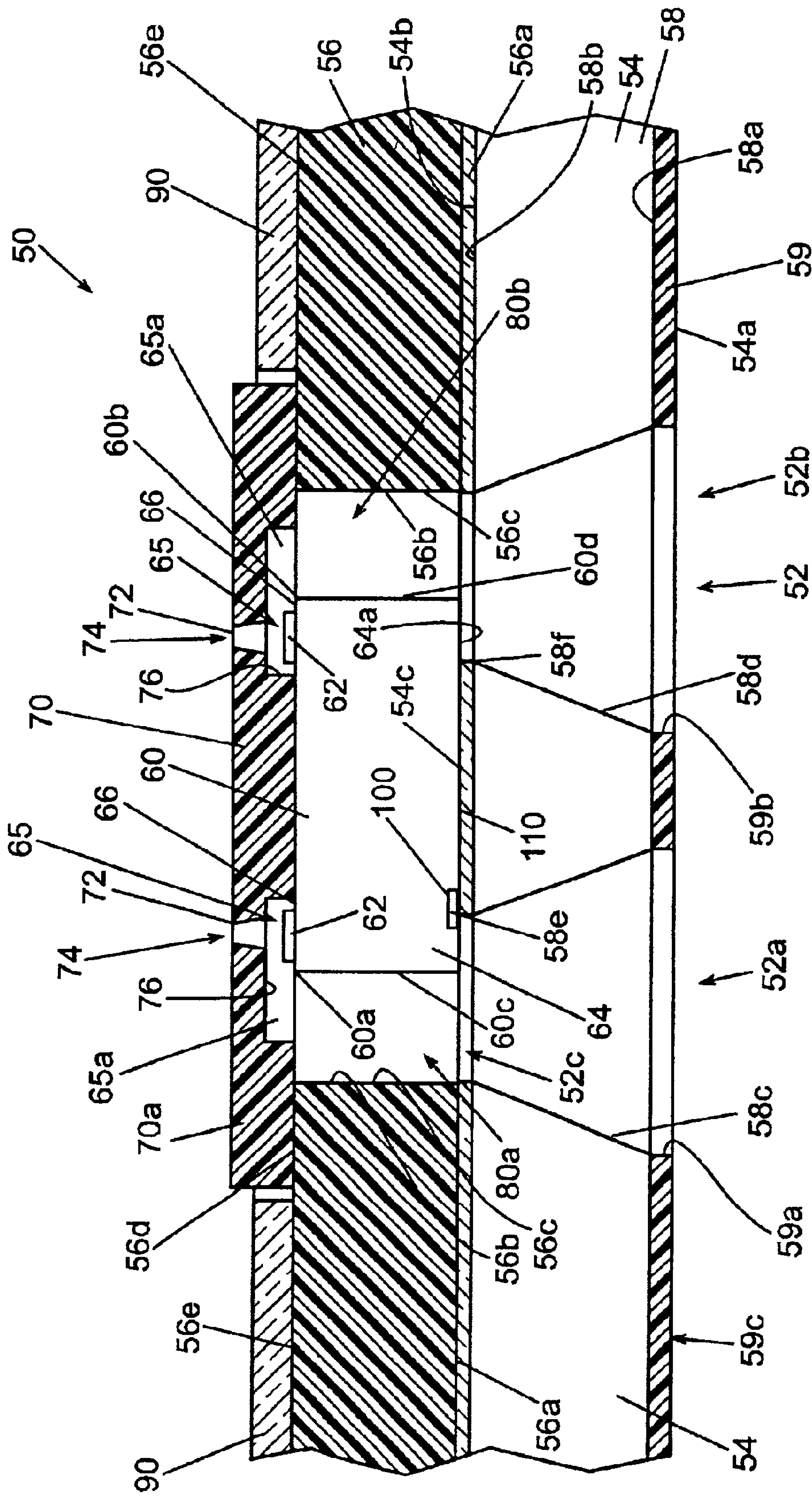


Fig. 2A

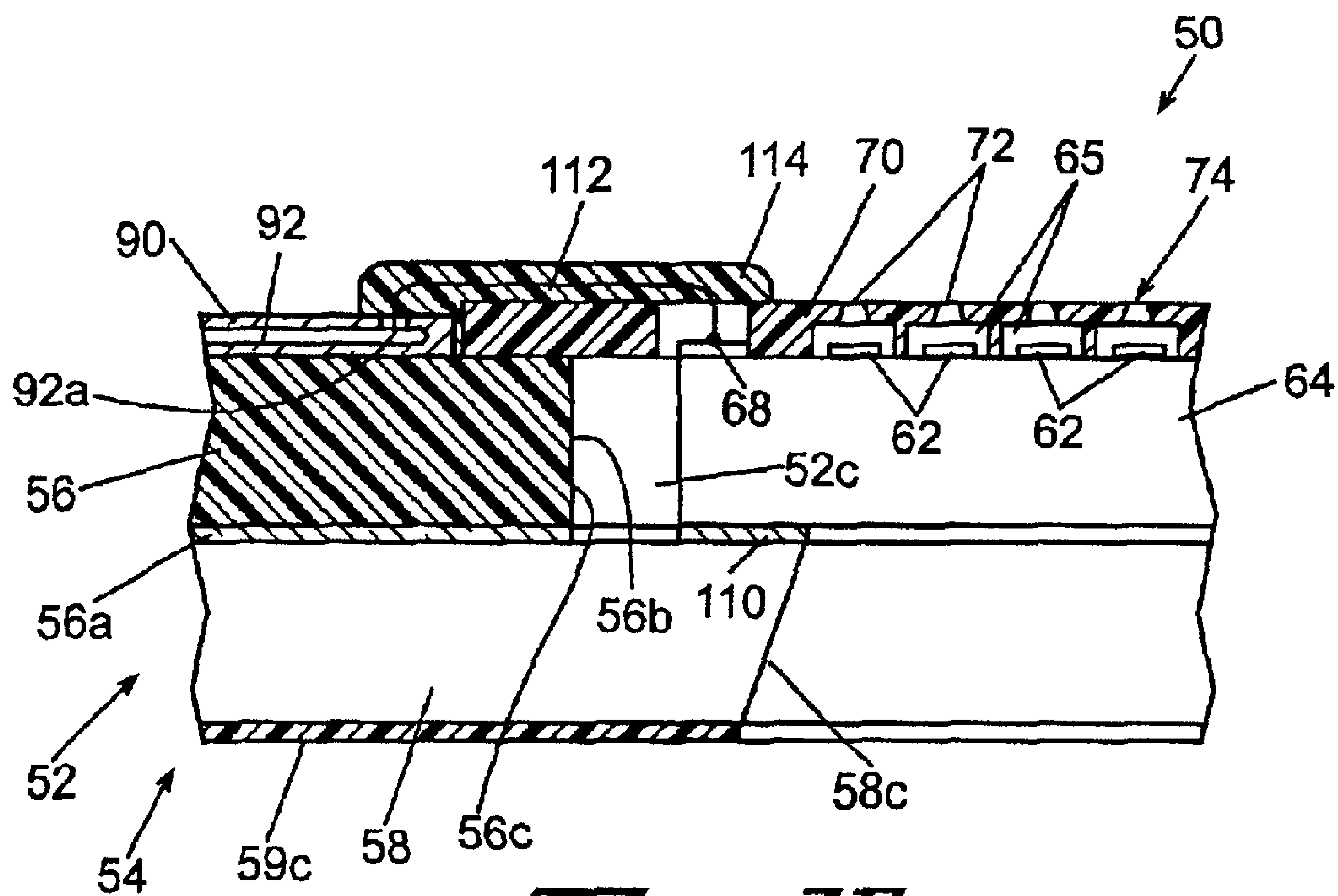


Fig. 2B

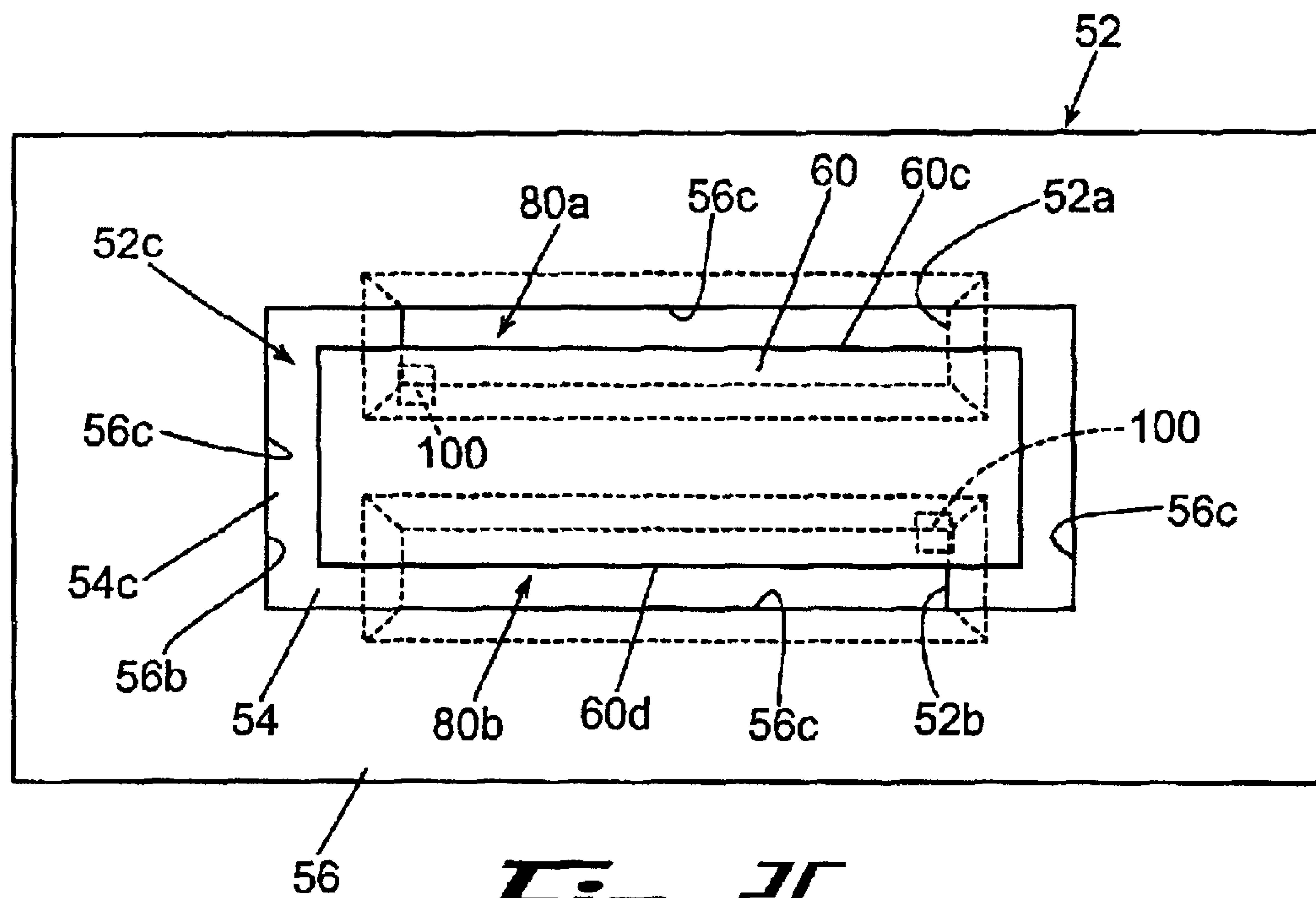


Fig. 2C

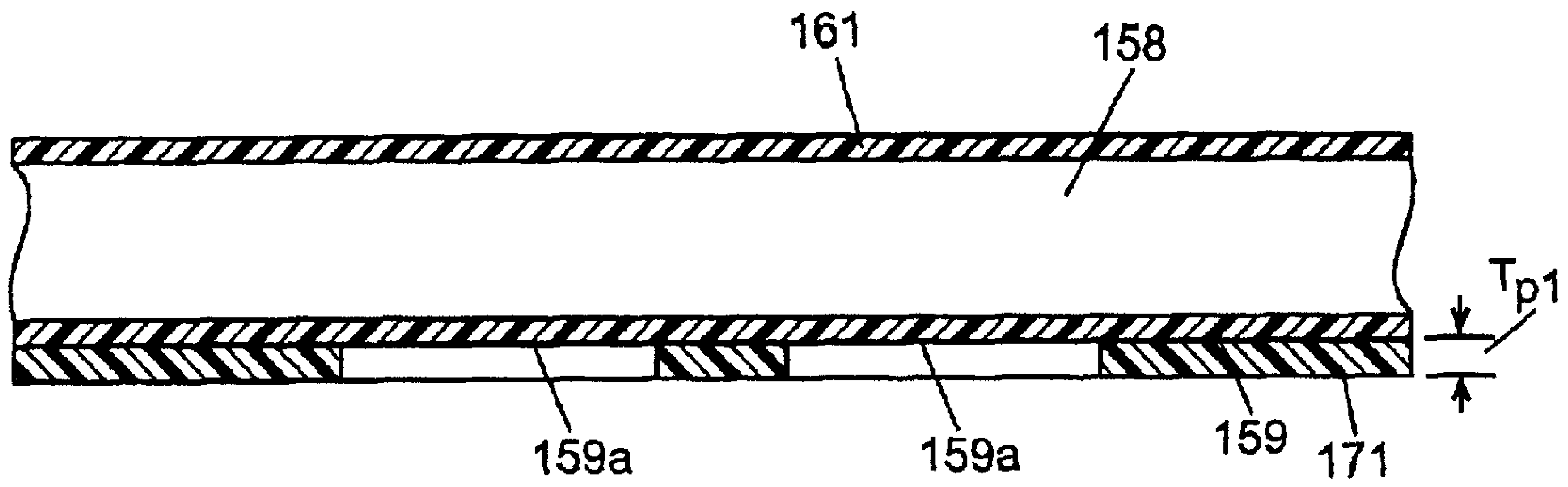


Fig. 4

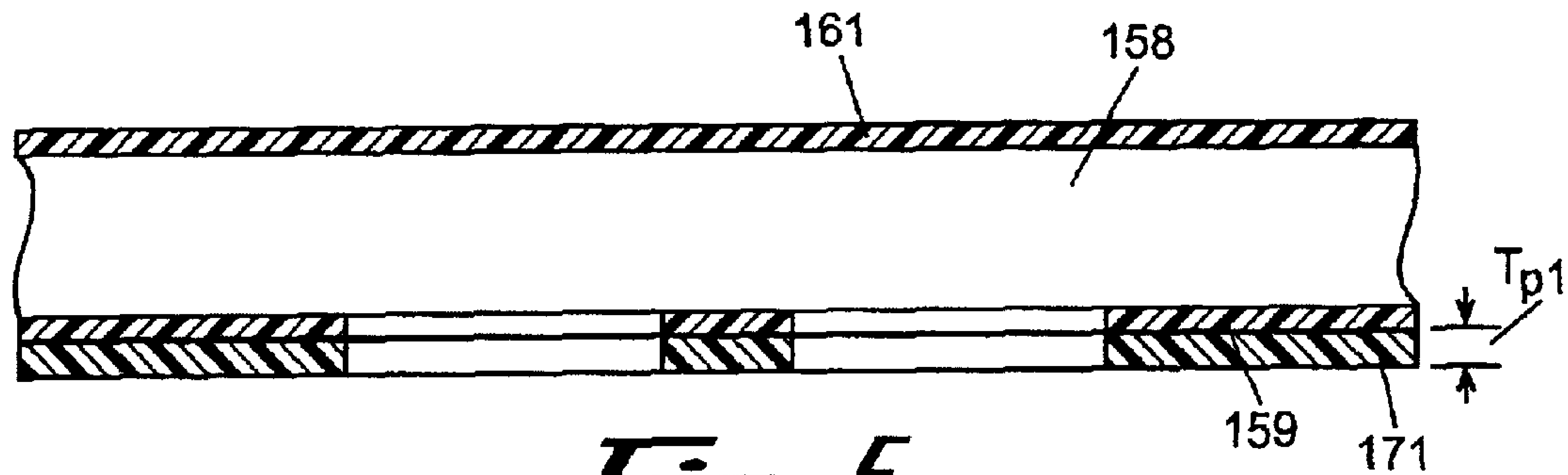


Fig. 5

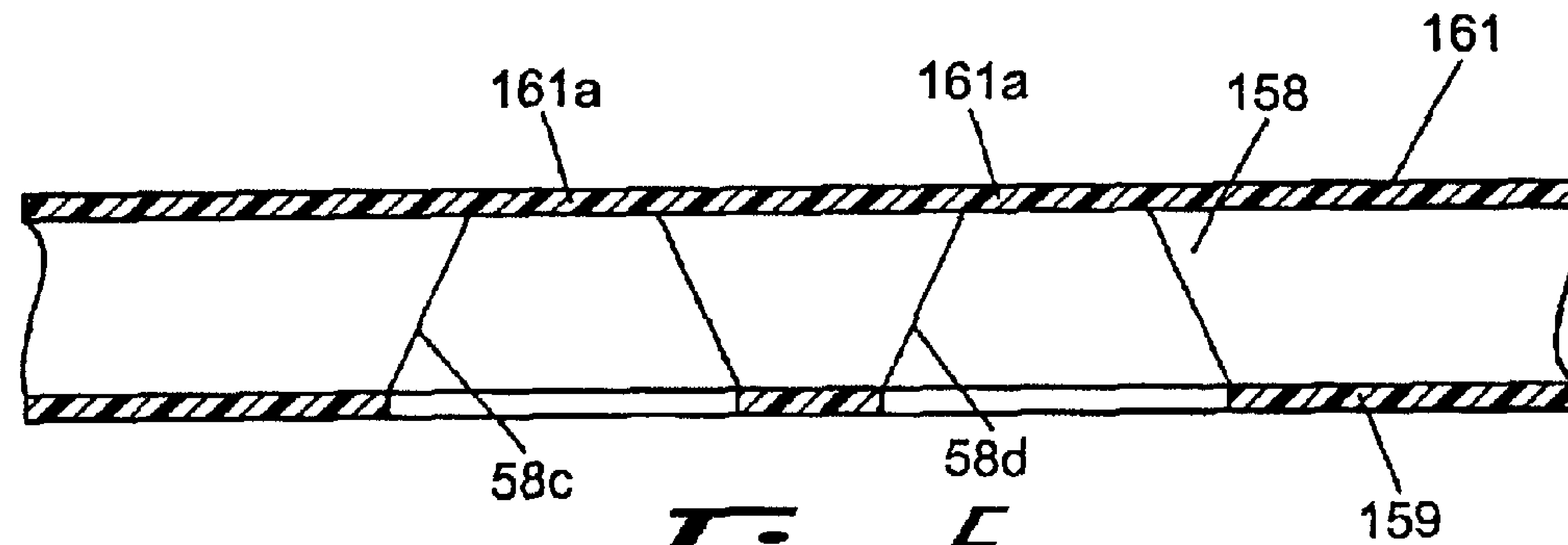


Fig. 6

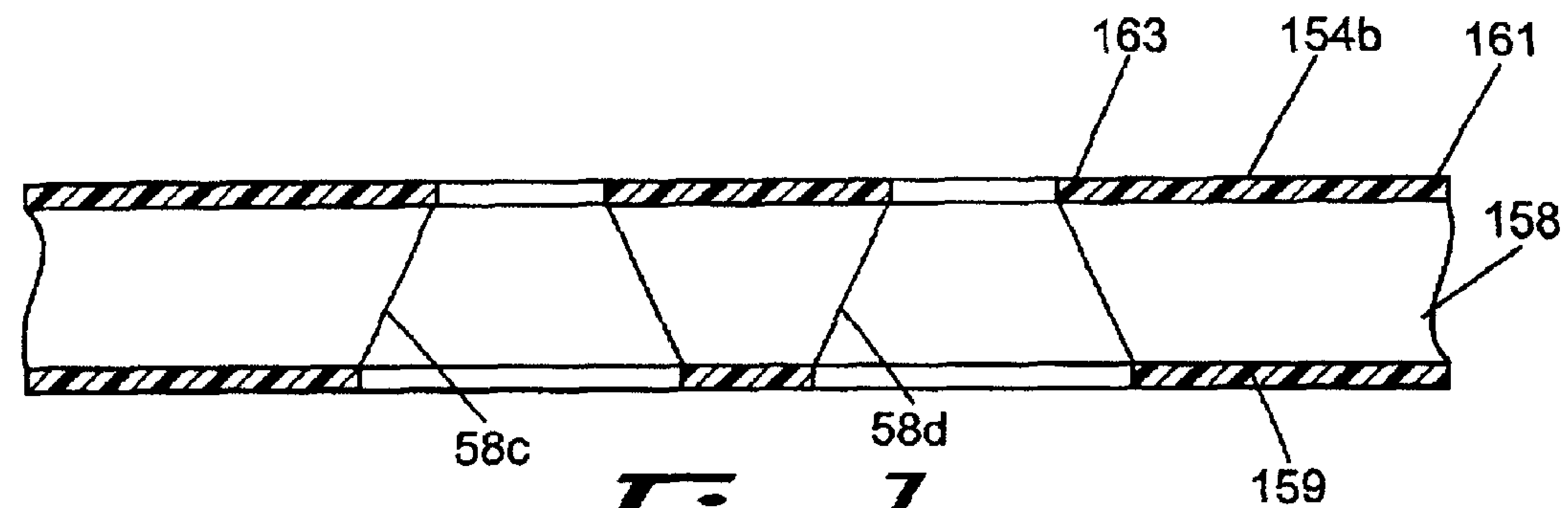


Fig. 7

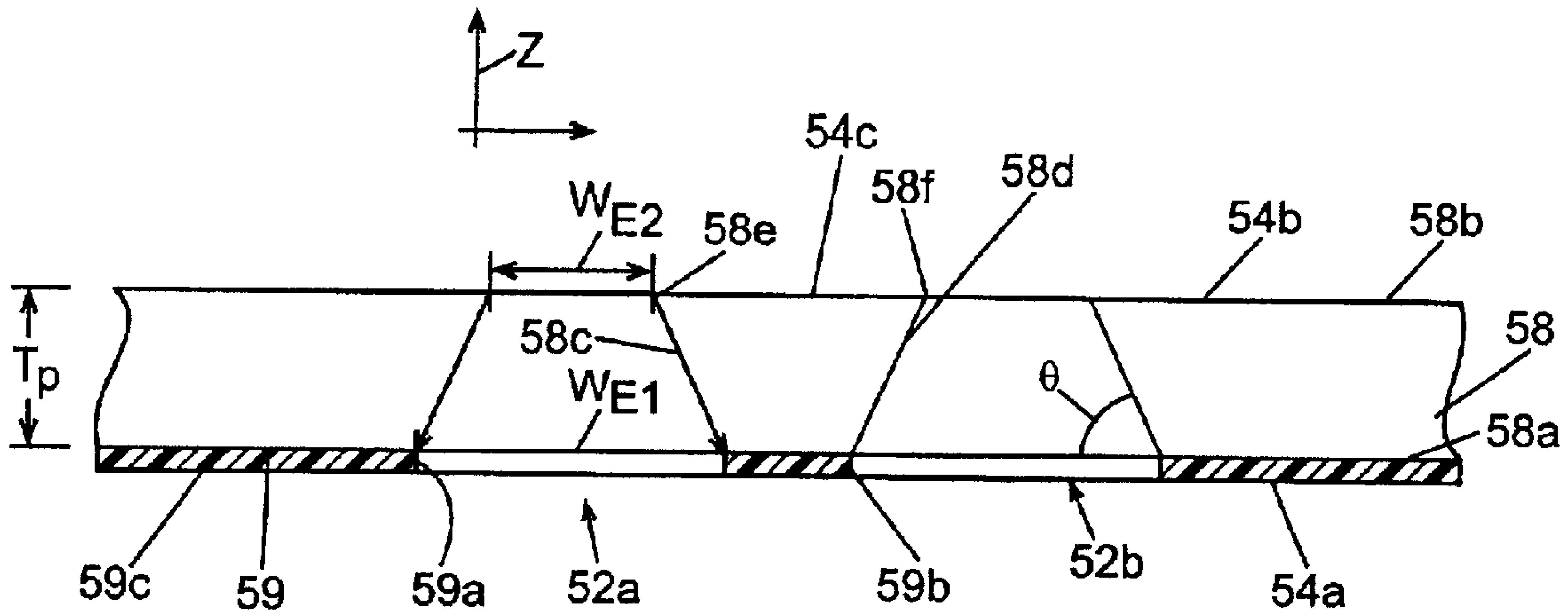


Fig. 8

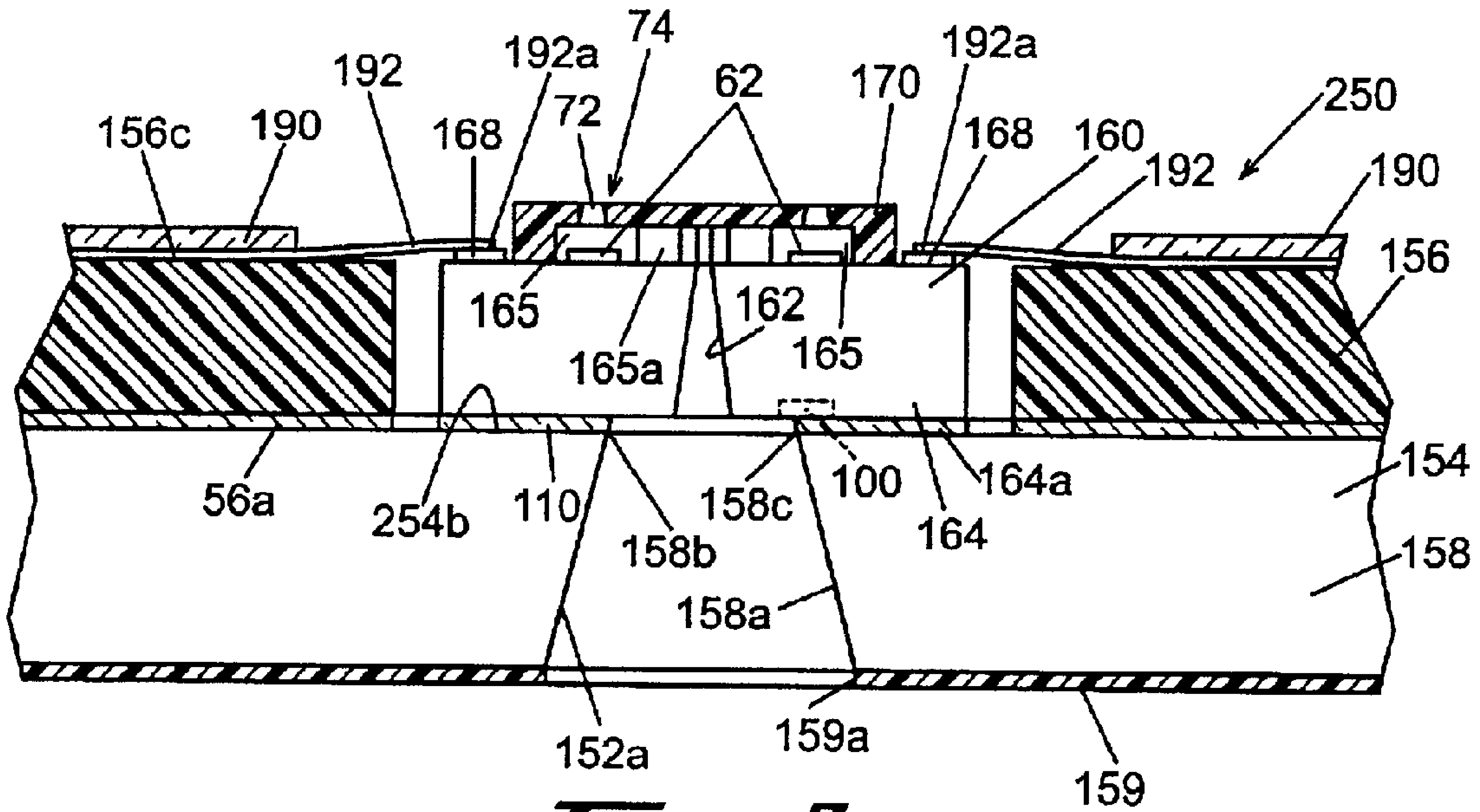


Fig. 9

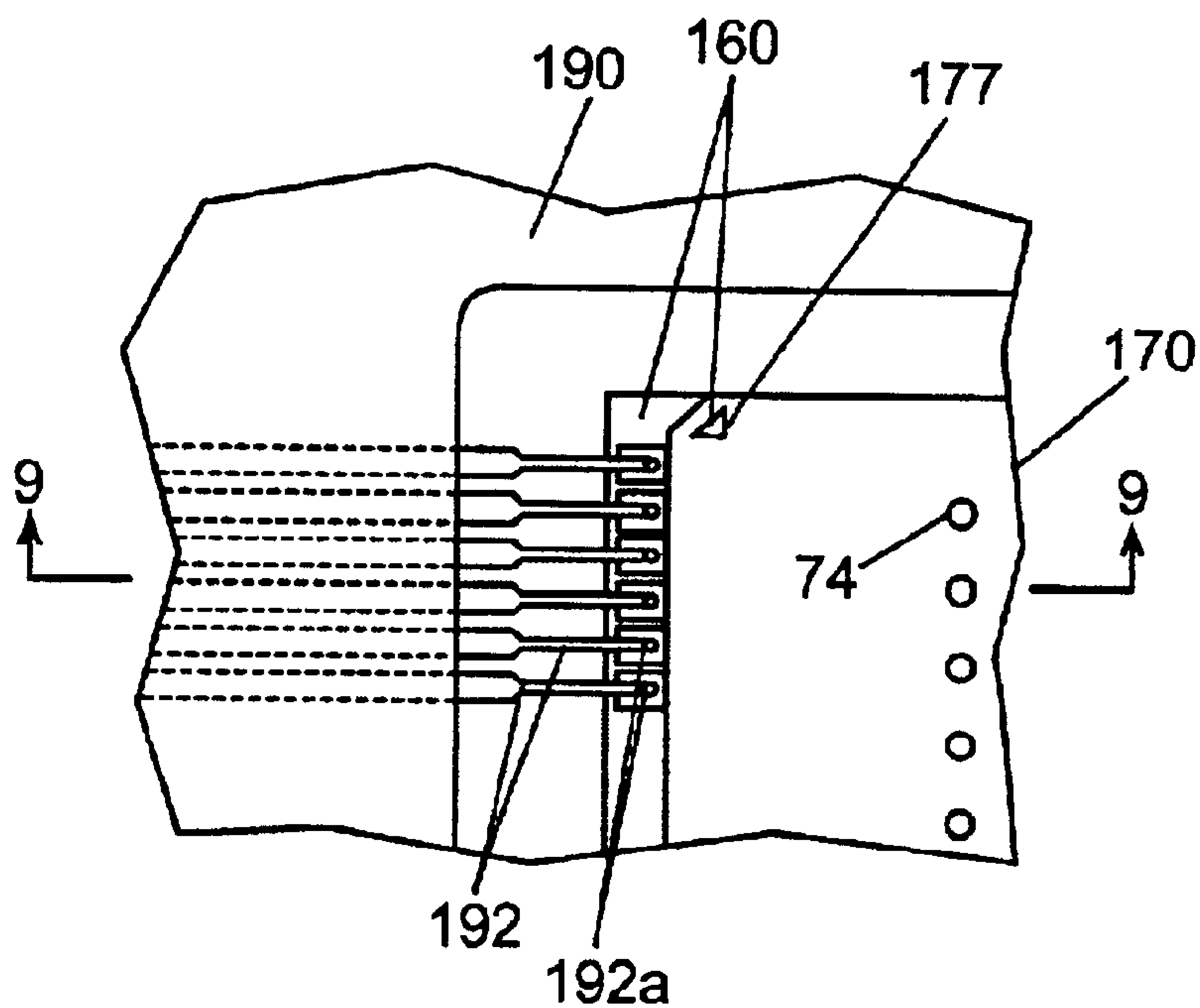


Fig. 10

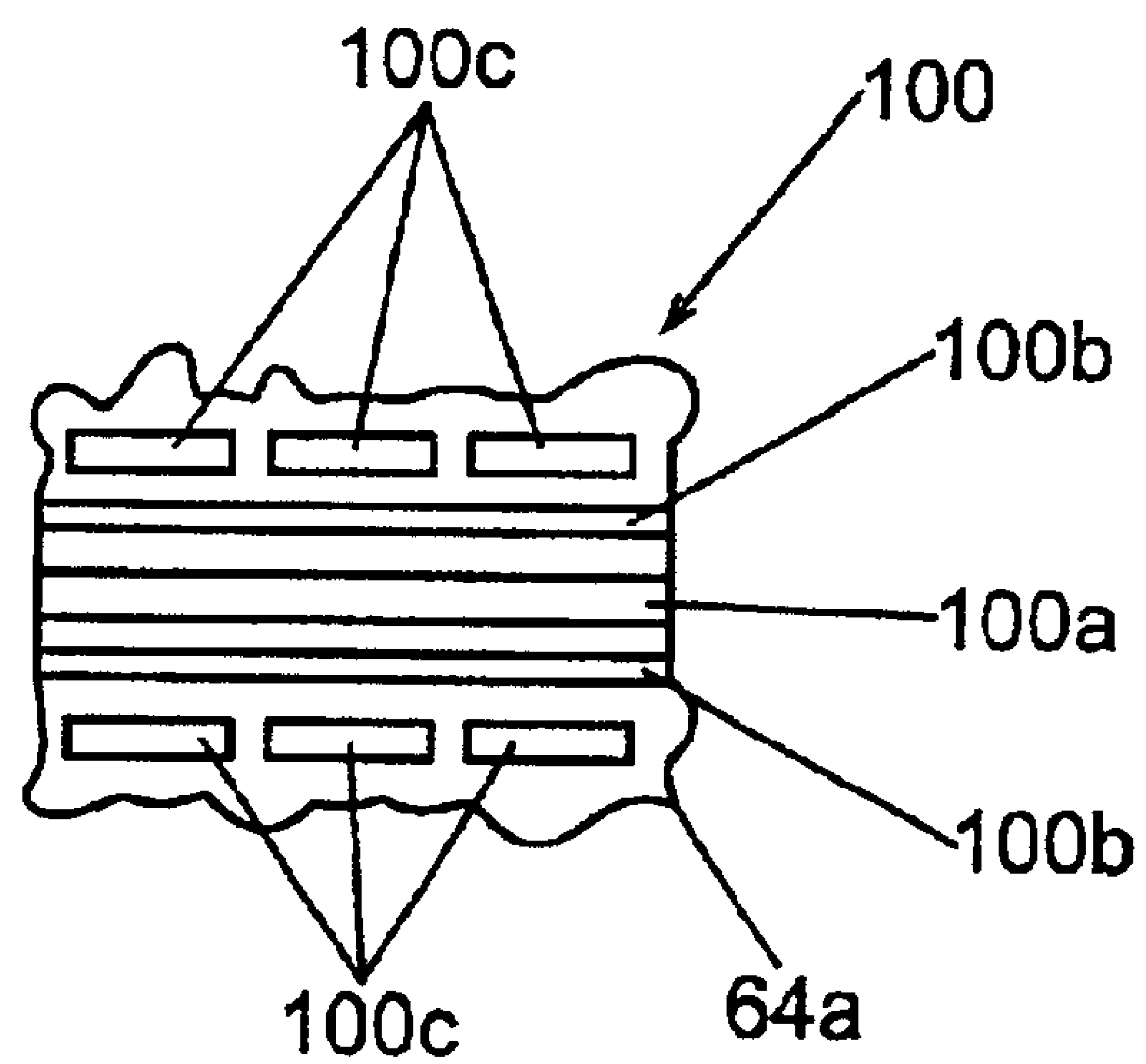


Fig. 11

PROCESS FOR MAKING A HEATER CHIP MODULE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a division of U.S. Ser. No. 09/099,854, filed Jun. 19, 1998, now U.S. Pat. No. 6,449,831, issued Sep. 17, 2002, entitled "PROCESS FOR MAKING A HEATER CHIP MODULE,", and is related to contemporaneously filed Patent Applications U.S. Ser. No. 09/100,070, now U.S. Pat. No. 6,267,472, issued Jul. 31, 2001, entitled "INK JET HEATER CHIP MODULE WITH SEALANT MATERIAL," U.S. Ser. No. 09/100,485, entitled "A HEATER CHIP MODULE AND PROCESS FOR MAKING SAME," U.S. Ser. No. 09/100,544, entitled "AN INK JET HEATER CHIP MODULE," U.S. Ser. No. 09/100,538, entitled "A HEATER CHIP MODULE FOR USE IN AN INK JET PRINTER," and U.S. Ser. No. 09/100,218, now U.S. Pat. No. 6,170,931, issued Jan. 9, 2001 entitled, "INK JET HEATER CHIP MODULE INCLUDING A NOZZLE PLATE COUPLING A HEATER CHIP TO A CARRIER," the disclosures of which are incorporated herein by inference.

FIELD OF THE INVENTION

This invention relates to a process for forming a heater chip module adapted to be secured to an ink-filled container.

BACKGROUND OF THE INVENTION

Drop-on-demand ink jet printers use thermal energy to produce a vapor bubble in an ink-filled chamber to expel a droplet. A thermal energy generator or heating element, usually a resistor, is located in the chamber on a heater chip near a discharge nozzle. A plurality of chambers, each provided with a single heating element, are provided in the printer's printhead. The printhead typically comprises the heater chip and a nozzle plate having a plurality of the discharge nozzles formed therein. The printhead forms part of an ink jet print cartridge which also comprises an ink-filled container.

A plurality of dots comprising a swath of printed data are printed as the ink jet print cartridge makes a single scan across a print medium, such as a sheet of paper. The data swath has a given length and width. The length of the data swath, which extends transversely to the scan direction, is determined by the size of the heater chip.

Printer manufacturers are constantly searching for techniques which may be used to improve printing speed. One possible solution involves using larger heater chips. Larger heater chips, however, are costly to manufacture. Heater chips are typically formed on a silicon wafer having a generally circular shape. As the normally rectangular heater chips get larger, less of the silicon wafer can be utilized in making heater chips. Further, as heater chip size increases, the likelihood that a chip will have a defective heating element, conductor or other element formed thereon also increases. Thus, manufacturing yields decrease as heater chip size increases.

Accordingly, there is a need for an improved printhead or printhead assembly which allows for increased printing speed yet is capable of being manufactured in an economical manner.

SUMMARY OF THE INVENTION

In accordance with the present invention, a process is provided for forming a heater chip module comprising a

carrier adapted to be secured to an ink-filled container, at least one heater chip having a base coupled to the carrier, and at least one nozzle plate coupled to the heater chip. The carrier includes a support substrate having at least one passage which defines a path for ink to travel from the container to the heater chip. The heater chip is secured at its base to a portion of the support substrate. A flexible circuit is coupled to the heater chip module such as by TAB bonding or wire bonding.

Two or more heater chips, positioned end to end, side by side or at an angle to one another, may be secured to a single support substrate.

Each of two or more heater chips coupled to a single support substrate may be dedicated to a different color. For example, three heater chips positioned side by side may be coupled to a single support substrate, wherein each heater chip receives ink of one of the three primary colors.

At least the portion of the support substrate is formed from a material having substantially the same coefficient of thermal expansion as the heater chip base. Thus, the heater chip base and the support substrate portion expand and contract at essentially the same rate. This is advantageous for a number of reasons. First, it is less likely that bonding material joining the heater chip to the carrier will fail. Further, if two or more heater chips are secured to the carrier, accuracy of dot placement is increased as the location of the heater chips relative to the paper is less likely to vary. It is also preferred that the support substrate portion be formed from a material having a thermal conductivity which is substantially the same as or greater than the thermal conductivity of the material from which the heater chip base is formed. Hence, the carrier provides a dissipation path for heat generated by the heater chip. Consequently, heat build up in the heater chip, which might occur if the thermal conductivity of the support substrate portion is less than that of the heater chip base, is avoided.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view, partially broken away, of an ink jet printing apparatus having a print cartridge constructed in accordance with the present invention;

FIG. **2** is a plan view of a portion of a heater chip module constructed in accordance with a first embodiment of the present invention;

FIG. **2A** is a view taken along view line **2A—2A** in FIG. **2**;

FIG. **2B** is a view taken along view line **2B—2B** in FIG. **2**;

FIG. **2C** is a plan view of the support substrate, spacer and heater chip of the module illustrated in FIGS. **2**, **2A** and **2B** with the nozzle plate and flexible circuit removed;

FIGS. **3–7** are schematic cross sectional views illustrating the process for forming the support substrate illustrated in FIGS. **2A** and **2B**;

FIG. **8** is a cross sectional view of a portion of the support substrate of the heater chip module of FIGS. **2**, **2A** and **2B**;

FIG. **9** is a cross sectional view of a portion of a heater chip module constructed in accordance with a second embodiment of the present invention;

FIG. **10** is a plan view of a portion of the heater chip module illustrated in FIG. **9**; and

FIG. **11** is a plan view of a marker on the bottom surface of a heater chip.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to FIG. **1**, there is shown an ink jet printing apparatus **10** having a print cartridge **20** constructed in

accordance with the present invention. The cartridge **20** is supported in a carriage **40** which, in turn, is slidably supported on a guide rail **42**. A drive mechanism **44** is provided for effecting reciprocating movement of the carriage **40** and the print cartridge **20** back and forth along the guide rail **42**. As the print cartridge **20** moves back and forth, it ejects ink droplets onto a paper substrate **12** provided below it.

The print cartridge **20** comprises a container **22**, shown only in FIG. **1**, filled with ink and a heater chip module **50**. The container **22** may be formed from a polymeric material. In the illustrated embodiment, the container **22** is formed from polyphenylene oxide, which is commercially available from the General Electric Company under the trademark "NORYL SE-1." The container **22** may be formed from other materials not explicitly set out herein.

In the embodiment illustrated in FIGS. **2**, **2**A and **2**B, the module **50** comprises a carrier **52**, an edge-feed heater chip **60** and a nozzle plate **70**. The heater chip **60** includes a plurality of resistive heating elements **62** which are located on a base **64**, see FIG. **2**A. In the illustrated embodiment, the base **64** is formed from silicon. The nozzle plate **70** has a plurality of openings **72** extending through it which define a plurality of nozzles **74** through which ink droplets are ejected. The carrier **52** is secured directly to a bottom side (not shown) of the container **22**, i.e., the side in FIG. **1** closest to the paper substrate **12**, such as by an adhesive (not shown). Thus, in the illustrated embodiment, there is no other element positioned between the carrier **52** and the container **22** except for the adhesive bonding the two elements together. An example adhesive which may be used for securing the carrier **52** to the container **22** is one which is commercially available from Emerson and Cuming Specialty Polymers, a division of National Starch and Chemical Company under the product designation "ECCOBOND 3193-17."

The nozzle plate **70** may be formed from a flexible polymeric material substrate which is adhered to the heater chip **60** via an adhesive (not shown). Examples of polymeric materials from which the nozzle plate **70** may be formed and adhesives for securing the plate **70** to the heater chip **60** are set out in commonly assigned patent applications, U.S. Ser. No. 08/966,281, entitled "METHOD OF FORMING AN INKJET PRINTHEAD NOZZLE STRUCTURE," by Ashok Murthy et al., filed on Nov. 7, 1997, which is a continuation-in-part application of U.S. Ser. No 08/519,906, entitled "METHOD OF FORMING AN INKJET PRINTHEAD NOZZLE STRUCTURE," by Tonya H. Jackson et al., filed on Aug. 28, 1995, the disclosures of which are hereby incorporated by reference. As noted therein, the plate **70** may be formed from a polymeric material such as polyimide, polyester, fluorocarbon polymer, or polycarbonate, which is preferably about 15 to about 200 microns thick, and most preferably about 20 to about 80 microns thick. Examples of commercially available nozzle plate materials include a polyimide material available from E. I. DuPont de Nemours & Co. under the trademark "KAPTON" and a polyimide material available from Ube (of Japan) under the trademark "UPILEX." The adhesive for securing the plate **70** to the heater chip **60** may comprise a phenolic butyral adhesive. A polyimide substrate/phenolic butyral adhesive composite material is commercially available from Rogers Corporation, Chandler, Ariz., under the product name "RFLEX 1100."

The nozzle plate **70** may be bonded to the chip **60** via any art recognized technique, including a thermocompression bonding process. When the plate **70** and the heater chip **60** are joined together, sections **76** of the plate **70** and portions **66** of the heater chip **60** define a plurality of bubble chambers **65**. Ink supplied by the container **22** flows into the bubble chambers **65** through ink supply channels **65*a***. As is illustrated in FIG. **2**A, the supply channels **65*a*** extend from the bubble chambers **65** beyond first and second outer edges **60*a*** and **60*b*** of the heater chip **60**. The resistive heating elements **62** are positioned on the heater chip **60** such that each bubble chamber **65** has only one heating element **62**. Each bubble chamber **65** communicates with one nozzle **74**.

The carrier **52** comprises a support substrate **54** and a spacer **56**, see FIGS. **2**A and **2**B. The support substrate **54** includes a silicon plate **58** having first and second outer surfaces **58*a*** and **58*b***, see FIGS. **2**A and **8**. The silicon plate **58** is also referred to herein as a portion of the support substrate **54**. The plate **58** has a thickness T_p of from about 400 microns to about 2500 microns and, preferably, from about 500 microns to about 1000 microns. First and second passages **58*c*** and **58*d*** extend through the silicon plate **58**. In the illustrated embodiment, the passages **58*c*** and **58*d*** are generally rectangular where they meet the first and second outer surfaces **58*a*** and **58*b***. They also converge inwardly from the first outer surface **58*a*** to the second outer surface **58*b***. Alternatively, the passages **58*c*** and **58*d*** may be oval, elliptical or have another geometric shape.

A first etch resistant material layer **59** is formed on the first outer surface **58*a*** of the silicon plate **58**, see FIG. **8**. The first layer **59** may be formed from any one of a number of known etch resistant materials including, for example, silicon nitride, silicon carbide, aluminum, tantalum, and silicon dioxide. Other materials not explicitly set out herein may also be used when forming the layer **59**. The first layer **59** has a thickness in the Z-direction, see FIG. **8**, of from about 1 micron to about 20 microns, including all ranges subsumed therein, and preferably from about 1 micron to about 2.5 microns.

The first layer **59** includes first and second openings **59*a*** and **59*b*** extending completely through it which communicates with the passages **58*c*** and **58*d***. The first opening **59*a*** has generally the same shape and size as the first passage **58*c*** where the passage **58*c*** meets the first silicon plate surface **58*a***. The second opening **59*b*** has generally the same shape and size as the second passage **58*d*** where the passage **58*d*** meets the first silicon plate surface **58*a***. The first and second silicon plate passages **58*c*** and **58*d*** and the first and second first layer openings **59*a*** and **59*b*** define first and second passages **52*a*** and **52*b*** in the support substrate **54**. An outer surface **59*c*** of the first layer **59** defines a first outer surface **54*a*** of the support substrate **54**. The second outer surface **58*b*** of the silicon plate **58** defines a second outer surface **54*b*** of the support substrate **54**.

The spacer **56** is formed from a material selected from group consisting of ceramics, metals, silicon and polymers. It is secured to the support substrate **54** by an adhesive **56*a***. Example adhesives which may be used for securing the spacer **56** to the support substrate **54** include a thermally curable B-stage adhesive (polysulfone) film preform which is commercially available from Alpha Metals Inc. under the product designation "Staystik 415" and another adhesive material which is commercially available from Mitsui Toatsu Chemicals Inc. under the product designation "REGULUS."

The spacer **56** has, in the illustrated embodiment, a generally rectangular opening **56*b*** defined by four inner side walls **56*c***, see FIG. **2**C. A central section **54*c*** of the second outer surface **54*b*** of the support substrate **54** and the inner side walls **56*c*** of the spacer **56** define an inner cavity **52*c*** of

the carrier **52**, see FIGS. **2**C and **8**. The heater chip **60** is located in the carrier inner cavity **52***c* and secured to the second surface **54***b* of the support substrate **54**. As can be seen from FIG. **2**A, the first and second support substrate passages **52***a* and **52***b* communicate with the inner cavity **52***c*.

The inner cavity **52***c* and the heater chip **60** are sized such that opposing side portions **60***c* and **60***d* of the heater chip **60** are spaced from adjacent inner side walls **56***c* of the spacer **56** to form gaps **80***a* and **80***b* of sufficient size to permit ink to flow freely between the chip side portions **60***c* and **60***d* and the adjacent inner side walls **56***c*, see FIG. **2**C.

The nozzle plate **70** is sized to extend over an outer portion **56***d* of the spacer **56** surrounding the opening **56***b* such that the inner cavity **52***c* is sealed to prevent ink from leaking from the inner cavity **52***c*, see FIG. **2**A. The passages **52***a* and **52***b* provide a path for ink to travel from the container **22** to the inner cavity **52***c*. From the inner cavity **52***c*, the ink flows into the ink supply channels **65***a*.

The resistive heating elements **62** are individually addressed by voltage pulses provided by a printer energy supply circuit (not shown). Each voltage pulse is applied to one of the heating elements **62** to momentarily vaporize the ink in contact with that heating element **62** to form a bubble within the bubble chamber **65** in which the heating element **62** is located. The function of the bubble is to displace ink within the bubble chamber **65** such that a droplet of ink is expelled from a nozzle **74** associated with the bubble chamber **65**.

A flexible circuit **90**, secured to the polymeric container **22** and the spacer **56**, is used to provide a path for energy pulses to travel from the printer energy supply circuit to the heater chip **60**. Bond pads **68** on the heater chip **60** are wire-bonded to sections **92***a* of traces **92** in the flexible circuit **90**, see FIGS. **2** and **2**B. Current flows from the printer energy supply circuit to the traces **92** on the flexible circuit **90** and from the traces **92** to the bond pads **68** on the heater chip **60**. Conductors (not shown) are formed on the heater chip base **64** and extend from the bond pads **68** to the heating elements **62**. The current flows from the bond pads **68** along the conductors to the heating elements **62**.

The process for forming the support substrate **54** will now be described with reference to FIGS. **3**–**7**. A silicon wafer **158** having a thickness T_p of from about 400 microns to about 2500 microns and preferably from about 500 microns to about 1000 microns is provided. The thickness of the wafer **158** is not critical and may fall outside of this range. A plurality of support substrates **54** are formed on a single wafer **158**. For ease of illustration, only a portion of the wafer **158** is illustrated in FIGS. **3**–**7**.

First and second etch resistant material layers **159** and **161** are formed on first and second sides **158***a* and **158***b* of the wafer **158**, see FIG. **3**. The layers **159** and **161** may be formed from any one of a number of known etch resistant materials including, for example, silicon nitride, silicon carbide, aluminum, tantalum, silicon dioxide, and the like. In the illustrated embodiment, silicon nitride is deposited simultaneously onto the outer surfaces of the wafer **158** using a conventional low-pressure vapor deposition process or a plasma enhanced chemical vapor deposition process. Alternatively, silicon dioxide layers may be thermally grown on the wafer **158**, or aluminum or tantalum layers may be formed on the opposing wafer surfaces via a conventional sputter or evaporation process.

The first layer **159** has a thickness in the Z-direction, see FIG. **3**, of from about 1 micron to about 20 microns, and preferably from about 1.0 micron to about 2.5 microns. The second layer **161** has a thickness in the Z-direction of from about 1 micron to about 20 microns, and preferably from about 1.0 micron to about 2.5 microns.

After the first and second layers **159** and **161** are deposited onto the wafer **158**, a first photoresist layer **171** is formed over the first etch resistant material layer **159** via a conventional spinning process. The layer **171** has a thickness of T_{P1} of from about 100 angstroms to about 50 microns, and preferably from about 1.0 micron to about 5.0 microns. The photoresist material may be a negative or a positive photoresist material. In the illustrated embodiment, the layer **171** is formed from a negative photoresist material which is commercially available from Olin Microelectronic Materials under the product designation "SC-100 Resist." After the photoresist layer **171** is spun onto the wafer **158**, it is softbaked at an appropriate temperature so as to partially evaporate photoresist solvents to promote adhesion of the layer **171** to the first layer **159**. A further reason for softbaking the layer **171** is to prevent a first mask, to be discussed below, from adhering to the layer **171**.

A first mask (not shown), having a plurality of blocked or covered areas which correspond to the first and second openings **59***a* and **59***b* in the first layer **59**, is positioned over the first photoresist layer **171**. The first mask is aligned in a conventional manner such as to the wafer flat (not shown). Thereafter, unblocked portions of the first photoresist layer **171** are exposed to ultraviolet light to effect curing or polymerization of the exposed portions. The first mask is then removed. Thereafter, the unexposed or uncured portions of the first photoresist layer **171** are removed using a conventional developer chemical. In the illustrated embodiment, the unpolymerized portions are removed by spraying a developer, such as one which is commercially available from Olin Microelectronic Materials under the product designation "PF developer," onto the first wafer side while the wafer **158** is spinning. After the development process has been initiated, a mixture of about 90% developer chemical and 10% isopropyl alcohol, by volume, is sprayed onto the first side of the spinning wafer **158**. Finally, the development process is stopped by spraying only isopropyl alcohol onto the spinning wafer **158**. After the unpolymerized portions of the first photoresist layer **171** are removed from the wafer **158**, portions **159***a* of the first etch resistant material layer **159** are exposed, see FIG. **4**.

Instead of spraying the three different development compositions onto the wafer **158**, the wafer **158** may be sequentially placed in three baths containing, respectively, 100% developer, a mixture of about 90% developer and 10% isopropyl alcohol, and 100% isopropyl alcohol. The wafer **158** remains in the first bath until the development process has been initiated. It is removed from the second bath and placed in the third bath after the unpolymerized portions of the first layer **171** have been removed. The wafer **158** is preferably agitated when in each of the baths.

Following the development of the first photoresist layer **171**, the first layer **171** is hardbaked in a conventional manner so as to effect final evaporation of remaining solvents in the layer **171**.

The pattern formed in the first photoresist layer **171** is transferred to the first etch resistant material layer **159**, see FIG. **5**, using a conventional etching process. For example, a conventional reactive ion etching process may be used. When the first etch resistant material layer **159** is formed from silicon nitride, the reactive gas supplied to the reactive ion etcher is CF_4. For etching of aluminum, a chlorine gas

may be supplied. When the layer **159** is formed from tantalum, a CF_4 gas is preferably provided.

After the pattern has been transferred to the first etch resistant material layer **159**, the polymerized photoresist material remaining on the wafer **158** is removed in a conventional manner. For example, a conventional reactive ion etcher receiving an O_2 plasma may be used. Alternatively, a commercially available resist stripper such as one which is available from Olin Microelectronic Materials under the product designation "Microstrip" may be used.

Next, a micromachining step is implemented to form the passages **58***c* and **58***d* in the silicon wafer **158**. This step involves placing the wafer **158** in an etchant bath such that exposed portions of the silicon are etched away. A tetramethyl ammonium hydroxide (TMAH) based bath may be used. The TMAH based bath comprises, by weight, from about 5% to about 40%, and preferably about 10% tetramethyl ammonium hydroxide, and from about 60% to about 95%, and preferably about 90%, water. The TMAH/water solution is passivated by dissolving silicon and/or silicic acid into the TMAH/water solution until the solution has a pH of from about 11 to about 13. A more detail discussion of passivating TMAH solutions can be found in the paper: U. Schnakenberg, W. Benecke, and P. Lange, *THAHW Etchants for Silicon Micromachining,"* In Proc. Int. Conf. on Solid State Sensors and Actuators (Transducers 1991), pages 815–818, San Francisco, June 1991, the disclosure of which is incorporated herein by reference. The passivated TMAH/water solution is advantageous as it will not attack a metal etch resistant layer. If the first etch resistant material layer **159** is formed from a non-metal, such as silicon nitride, a potassium hydroxide (KOH) based bath may be used. The KOH bath comprises, by weight, from about 5% to about 75%, and preferably about 45% potassium hydroxide, and from about 25% to about 95%, and preferably about 55% water.

Thus, if the first etch resistant material layer **159** is formed from a metal, such as aluminum or tantalum, a tetramethyl ammonium hydroxide (TMAH) based bath should be used as a KOH bath will attack the metal layer **159**. When sufficient etching has occurred such that the passages **58***c* and **58***d* are formed, see FIG. **6**, the wafer **158** is removed from the bath.

When a KOH solution is used, the following equations describe the resulting geometry of the passages **58***c* and **58***d:*

$$W_{E1}=W_{E2}+T_P(1.414)$$

$$L_{E1}=L_{E2}+T_p(1.414)$$

where W_{E1} is the width of the entrance of each of the passages **58***c* and **58***d*, see FIG. **8**;

W_{E2} is the width of the exit of each of the passages **58***c* and **58***d;*

L_{E1} is the length of the entrance of each of the passages **58***c* and **58***d*, where the length of the entrance extends transversely to the width of the entrance (not shown in the drawings but extends in and out of the paper as viewed in FIG. **8**); and

L_{E2} is the length of the exit of each of the passages **58***c* and **58***d*, where the length of the exit extends transversely to the width of the exit (not shown in the drawings but extends in and out of the paper as viewed in FIG. **8**).

When a TMAH solution is used, the following equations describe the resulting geometry of the passages **58***c* and **58***d:*

$$W_{E1}=W_{E2}+T_p(2/\tan Q)$$

$$L_{E1}=L_{E2}+T_p(2/\tan Q)$$

where W_{E1} is the width of the entrance of each of the passages **58***c* and **58***d;*

W_{E2} is the width of the exit of each of the passages **58***c* and **58***d;*

L_{E1} is the length of the entrance of each of the passages **58***c* and **58***d*, where the length extends transversely to the width of the entrance (not shown in the drawings but extends in and out of the paper as viewed in FIG. **8**);

L_{E2} is the length of the exit of each of the passages **58***c* and **58***d*, where the length extends transversely to the width of the exit (not shown in the drawings but extends in and out of the paper as viewed in FIG. **8**);

Q is the angle formed by a sidewall of each of the passages **58***c* and **58***d* and a horizontal plane, see FIG. **8**.

Thereafter, the second etch resistant material layer **161** is removed using a conventional reactive ion etcher. Alternatively, only sections **161***a* of the layer **161** may be removed during a wafer washing step using a conventional wafer washer, see FIGS. **6** and **7**. In this embodiment, an upper surface **163** of the second layer **161** defines the upper surface **154***b* of the support substrate **54**. Thus, the heater chip **60** is bonded to the upper surface **163** of the second layer **161** in this embodiment. If the entire second layer **161** is removed, the heater chip **60** is bonded to the second outer surface **58***b* of the silicon plate **58**.

After removal of the second layer **161** or sections **161***a* of the second layer **161**, the wafer **158** is diced into individual support substrates **54**.

The heater chip **60** is preferably formed with two alignment markers **100** on its bottom surface **64***a*, see FIG. **2**C. An alignment marker **100** formed in accordance with the present invention is illustrated in FIG. **11**. It comprises a center line **100***a*, two thinner side lines **100***b* positioned on opposite sides of the center line **100***a* and two dotted lines **100***c* positioned outside of the two side lines **100***b*. The center line **100***a* and the dotted lines each have a width of approximately 10 microns. The side lines **100***b* have a width of approximately 5 microns. The lines **100***a*, **100***b* and **100***c* are separated from one another by approximately 10 microns.

The markers **100** are formed in the following manner. A positive photoresist layer formed, for example, from a material commercially available from Shipley Company Inc. under the product designation "1827 Positive Resist" is spun onto an outer surface of a silicon wafer (not shown) to a thickness of approximately 3 microns. Typically, a plurality of heater chips **60** are formed on a single wafer. Preferably, the markers **100** are formed on the wafer after the heating elements, conductors and other elements of the heater chips are formed. After being spun onto the wafer, the photoresist layer is softbaked at an appropriate temperature so as to partially evaporate photoresist solvents.

A second mask (not shown), having a plurality of blocked or covered areas which correspond to background areas between the lines **100***a*, **100***b* and **100***c*, is positioned over the photoresist layer. The mask is aligned in a conventional manner such as by an infra-red mask aligner to two or more elements, e.g., heating elements or conductors, previously formed on the opposite side of the wafer. Thereafter, unblocked portions of the photoresist layer are exposed to ultraviolet light to change the chemical structure of the

photoresist material from relatively nonsoluble to much more soluble. The mask is then removed. Following removal of the mask, the photoresist layer is soaked in a chlorobenzene bath for approximately five minutes. The photoresist is then developed using, for example, a material commercially available from Shipley Co. Inc. under the product designation "Microposit MF319." During this development step, the photoresist layer portions exposed to the ultraviolet radiation are removed.

Following the development step, a layer of chromium is sputtered onto the wafer to a thickness of approximately 500 angstroms. The wafer is then soaked in acetone for approximately five minutes to remove the remaining photoresist material and portions of the chromium layer formed over the remaining photoresist material. The chromium material remaining after the acetone soaking process comprises the markers **100**.

The process for forming the heater chip module **50** illustrated in FIGS. **2**, **2**A and **2**B will now be described. As noted above, the nozzle plate **70** comprises a flexible polymeric material substrate. In the illustrated embodiment, the flexible substrate is provided with an overlaid layer of phenolic butyral adhesive for securing the nozzle plate **70** to the heater chip **60**.

Initially, the nozzle plate **70** is aligned with and mounted to the heater chip **60**. At this point, the heater chip **60** has been separated from other heater chips **60** formed on the same wafer. Alignment may take place as follows. One or more first fiducials (not shown) may be provided on the nozzle plate **70** which are aligned with one or more second fiducials (not shown) provided on the heater chip **60**. After the nozzle plate **70** is aligned to and located on the heater chip **60**, the plate **70** is tacked to the heater chip **60** using, for example, a conventional thermocompression bonding process. The phenolic butyral adhesive on the nozzle plate **70** is not fully cured after the tacking step has been completed.

Either before or after the nozzle plate **70** is tacked to the heater chip **60**, the spacer **56** is bonded to the support substrate **54**. At this juncture, the support substrate **54** has been separated from other support substrates **54** formed on the same wafer. A layer of the adhesive **56***a*, examples of which are noted above, is applied to the second outer surface **54***b* of the support substrate **54** where the spacer **56** is to be positioned. The spacer **56** is then mounted to the support substrate **54**. Thereafter, the adhesive **56***a* is fully cured using heat and pressure.

A further adhesive material (not shown), such as a 0.002 inch die-cut phenolic adhesive film, which is commercially available from Rogers Corporation (Chandler, Ariz.) under the product designation "1000B200," is placed on a portion **56***e* of the spacer **56** to which the flexible circuit **90** is to be secured. Thereafter, the flexible circuit **90** is positioned over the adhesive film and tacked to the spacer **56** using heat and pressure. In the illustrated embodiment, the flexible circuit **90** is coupled to the spacer **56** after the spacer **56** has been bonded to the support substrate **54**. It is also contemplated that the flexible circuit **90** may be coupled to the spacer **56** before the spacer **56** is secured to the support substrate **54**.

The nozzle plate/heater chip assembly is then mounted to the support substrate/spacer assembly. Initially, a conventional die bond adhesive **110**, such as a substantially transparent phenolic polymer adhesive which is commercially available from Georgia Pacific under the product designation "BKS 2600," is applied to the second outer surface **54***b* of the support substrate **54** at locations where one or more heater chips **60** are to be located. It is contemplated that one or two or more heater chips **60** may be secured to a single support substrate **54**. For example, two heater chips **60** may be positioned end to end, side by side or offset from one another on the support substrate **54**. Two heater chips **60** may be provided in the same or different inner cavities **52***c*. Thereafter, the two markers **100** on the bottom surface **64***a* of each heater chip **60** are aligned relative to inner edges **58***e* and **58***f* of the silicon plate **58**, see FIGS. **2**A and **8**. The heater chip **60** is in alignment when the center line **100***a* of one of its two markers **100** is positioned over edge **58***e* and the center line **100***a* of the other marker **100** is positioned over edge **58***f*. The markers **100** may be viewed using, for example, a video microscope (not shown) which generates an output signal provided to either a monitor for analysis by human vision or to an optical analyzer for analysis by an electronic device. It is also contemplated that an operator may view the markers **100** through an eyepiece of a standard microscope.

Alternatively, alignment markers (not shown), two for each heater chip **60**, may be formed on the second outer surface **54***b* of the support substrate **54**. The markers **100** on the heater chip **60** and the markers on the support substrate **54** are located respectively on the heater chip **60** and the support substrate **54** such that when the markers are in alignment with one another the heater chip **60** is properly aligned to the support substrate **54**. A conventional infra-red aligner may be used to effect alignment of the markers on the heater chip **60** and the support substrate **54**.

The nozzle plate/heater chip assembly is tacked to the support substrate/spacer assembly so as to maintain the two assemblies joined together until the die bond adhesive **110** is cured. Before the nozzle plate/heater chip assembly is mounted onto the support substrate/spacer assembly, a conventional ultraviolet (UV) curable adhesive (not shown), such as one which is commercially available from Emerson and Cuming Specialty Polymers, a division of National Starch and Chemical Company under the product designation UV9000, is applied to one or more locations on the support substrate **54** where corners of the heater chip **60** are to be located. After the nozzle plate/heater chip assembly is mounted to the support substrate/spacer assembly, exposed adhesive is cured using ultraviolet radiation to effect tacking.

Next, the nozzle plate/heater chip assembly and the support substrate/spacer assembly are heated in an oven at a temperature and for a time period sufficient to effect the curing of the following materials: the phenolic butyral adhesive that bonds the nozzle plate **70** to the heater chip **60** and the spacer **56**; the phenolic adhesive film which joins the flexible circuit **90** to the spacer **56**; and the die bond adhesive **110** which joins the heater chip **60** to the support substrate **54**. During the heating step, pressure may or may not be applied to the nozzle plate/heater chip assembly and the support substrate/spacer assembly.

After the nozzle plate/heater chip assembly and the flexible circuit **90** have been bonded to the support substrate/spacer assembly, sections **92***a* of the traces **92** on the flexible circuit **90** are wire-bonded to the bond pads **68** on the heater chip **60**, see FIGS. **2** and **2**B. A single wire **112** extends between each bond pad/trace section pair after wire-bonding has been completed. The wires **112** extend through windows or openings **71** formed in the nozzle plate **70**. It is also contemplated that the nozzle plate **70** may be sized so that the wires **112** do not extend through windows in the nozzle plate **70** such as described in the above referenced patent application entitled "AN INK JET HEATER CHIP MODULE WITH SEALANT MATERIAL." It is also contemplated that trace sections may be coupled to the bond pads **68** via a conventional Tape Automated Bonding (TAB)

process such as in the manner disclosed in the above referenced patent application entitled "AN INK JET HEATER CHIP MODULE INCLUDING A NOZZLE PLATE COUPLING A HEATER CHIP TO A CARRIER". After wire-bonding or TAB bonding, a liquid encapsulant material **114**, such as an ultraviolet (UV) curable adhesive, one of which is commercially available from Emerson and Cuming Specialty Polymers, a division of National Starch and Chemical Company under the product designation "UV9000," shown in FIG. 2B, is applied over the trace sections **92**a, the bond pads **68**, the wires **112** and the windows **71**. The UV adhesive is then cured using ultraviolet light.

The heater chip module **50**, which comprises the nozzle plate/heater chip assembly and the support substrate/spacer assembly, and to which the flexible circuit **90** is tacked, is aligned with and bonded directly to a polymeric container **22**. An adhesive (not shown) such as one which is commercially available from Emerson and Cuming Specialty Polymers, a division of National Starch and Chemical Company under the product designation "ECCOBOND 3193-17" is applied to a portion of the container where the module **50** is to be located. The module **50** is then mounted to the container portion.

Next, the heater chip module **50** and container **22** are heated in an oven at a temperature and for a time period sufficient to effect the curing of the adhesive that joins the heater chip module **50** to the container **22**.

A portion of the flexible circuit **90** which is not joined to the spacer **56** is bonded to the container **22** by, for example, a conventional free-standing pressure sensitive adhesive film, such as described in copending patent application U.S. Ser. No. 08/827,140, entitled "A PROCESS FOR JOINING A FLEXIBLE CIRCUIT TO A POLYMERIC CONTAINER AND FOR FORMING A BARRIER LAYER OVER SECTIONS OF THE FLEXIBLE CIRCUIT AND OTHER ELEMENTS USING AN ENCAPSULANT MATERIAL," filed Mar. 27, 1997, the disclosure of which is incorporated herein by reference.

It is also contemplated that the heater chip **60** may be secured to the support substrate **54** by silicon fusion bonding, eutectic bonding, or anodic bonding. In anodic bonding, a thin layer of sputtered glass is put down on the second outer surface **54**b of the support substrate **54** where the one or more heater chips **60** are to be secured. An example ionic glass material is one which is commercially available from Corning Inc. under the product designation "Glass Code 7440." Anodic bonding involves the application of heat and the simultaneous application of a high voltage across the support substrate **54** and the heater chip **60**.

A heater chip module **250**, formed in accordance with a second embodiment of the present invention, is shown in FIGS. **9** and **10**, wherein like reference numerals indicate like elements. Here, the support substrate **154** is formed having only one passage **152**a for each heater chip **160**. The heater chip **160** comprises a conventional center feed heater chip having a center ink-receiving via **162**. Ink from the container **22** travels through the passage **152**a in the support substrate **154** to the via **162**. From the via **162**, the ink passes through supply channels **165**a in the nozzle plate **170** to bubble channels **165** defined by portions of the heater chip **160** and sections of the nozzle plate **170**.

The support substrate **154** may be formed from substantially the same materials from which the support substrate **54** in the FIG. **2** embodiment is formed. Further, the process steps described above for forming the support substrate **54** may also be used when forming the support substrate **154**. However, only one passage **158**a is formed through the silicon plate **158** and one opening **159**a is formed in the first etch resistant layer **159** for each heater chip **160**.

Assembly of the components of the heater chip module **250** may occur in the following manner. Initially, the nozzle plate **170** is aligned with and mounted to the heater chip **160**. Typically, a plurality of heater chips **160** are formed on a single wafer. In this embodiment, a nozzle plate **170** is mounted to each heater chip **160** before the wafer is diced. Alignment may take place as follows. One or more first fiducials (not shown) may be provided on the nozzle plate **170** which are aligned with one or more second fiducials (not shown) provided on the heater chip **160**. After the nozzle plate **170** is aligned to and located on the heater chip **160**, the plate **170** is tacked to the heater chip **160**.

The nozzle plate **170** includes one or more openings **177** which, in the illustrated embodiment, are triangular in shape, see FIG. **10**. The openings **177** may be circular, square or have another geometric shape. An ultraviolet (UV) curable adhesive (not shown), such as one which is commercially available from Emerson and Cuming Specialty Polymers, a division of National Starch and Chemical Company under the product designation UV9000 is applied over the openings **177** so as to contact both the nozzle plate **170** and the heater chip **160**. Thereafter, the adhesive is cured using UV radiation to effect tacking. Each heater chip **160** on the heater chip wafer receives a nozzle plate **170** which is tacked to its corresponding heater chip **160** in this manner. After tacking has been completed, the nozzle plates **170** are permanently bonded to the heater chips **160** on the wafer by curing the layer of phenolic butyral adhesive provided on the underside of each nozzle plate **170** using, for example, a conventional thermocompression bonding process. Thereafter, the heater chip wafer is diced so as to separate the nozzle plate/heater chip assemblies from one another.

After the heater chip wafer has been diced, a flexible circuit **190** is attached to the heater chip **160** of each nozzle plate/heater chip assembly. End sections **192**a of traces **192** on the flexible circuit **190** are TAB bonded to the bond pads **168** on the heater chip **160**, see FIGS. **9** and **10**. It is also contemplated that trace sections may be coupled to the bond pads **168** via a wire-bonding process. However, such a wire-bonding step would most likely occur after the flexible circuit **190** is attached to the spacer **156**.

Either before or after the nozzle plate **170** is tacked to the heater chip **160**, the spacer **156** is bonded to the support substrate **154** using the same process and adhesive described above for bonding the spacer **56** to the support substrate **54**.

A further adhesive material (not shown), such as a 0.002 inch die-cut phenolic adhesive film, which is commercially available from Rogers Corporation under the product designation "1000B200," is placed on a portion **156**e of the spacer **156** to which the flexible circuit **190** is to be secured.

After the nozzle plate **170** has been bonded to the heater chip **160**, the spacer **156** has been bonded to the support substrate **154**, and the phenolic adhesive film has been placed on the spacer **156**, the nozzle plate/heater chip assembly is aligned with and tacked to the support substrate/spacer assembly. Initially, a die bond adhesive **110** is applied to the second outer surface **254**b of the support substrate **154** at a location where the heater chip **160** is to be located. A pair of markers **100**, formed on the bottom surface **164**a of the heater chip base **164** on opposite sides of the via **162**, are then aligned to inner edges **158**b and **158**c of the silicon plate **158**. The edges **158**b and **158**c define an outer edge of the passage **152**a.

The nozzle plate/heater chip assembly is tacked to the support substrate/spacer assembly so as the maintain the two assemblies joined together until the die bond adhesive **110** is cured. Before the nozzle plate/heater chip assembly is mounted onto the support substrate/spacer assembly, a conventional ultraviolet (UV) curable adhesive (not shown), such as one which is commercially available from Emerson and Cuming Specialty Polymers, a division of National Starch and Chemical Company under the product designation UV9000, is applied to one or more locations on the support substrate **154** where corners of the heater chip **160** are to be positioned. After the nozzle plate/heater chip assembly is mounted to the support substrate/spacer assembly, exposed adhesive is cured using ultraviolet radiation to effect tacking.

Once the nozzle plate/heater chip assembly is mounted to the support substrate/spacer assembly, the flexible circuit **190** contacts the phenolic adhesive film placed on the spacer **156**. The flexible circuit **190** is tacked to the spacer **156** using a conventional thermocompression bonding apparatus.

Next, the nozzle plate/heater chip assembly and the support substrate/spacer assembly are heated in an oven at a temperature and for a time period sufficient to effect the curing of the following materials: the phenolic adhesive film which joins the flexible is circuit **190** to the spacer **156** and the die bond adhesive **110** which joins the heater chip **160** to the support substrate **154**.

A liquid encapsulant material (not shown) such as an ultraviolet (UV) curable adhesive, one of which is commercially available from Emerson and Cuming Specialty Polymers, a division of National Starch and Chemical Company under the product designation UV9000, is then applied over the trace end sections **192***a* and the bond pads **168**. Thereafter, the UV adhesive is cured using UV light.

The heater chip module **250**, which comprises the nozzle plate/heater chip assembly and the support substrate/spacer assembly, and to which the flexible circuit **190** is tacked, is aligned with and bonded directly to a polymeric container **22**. An adhesive (not shown) such as one which is commercially available from Emerson and Cuming Specialty Polymers, a division of National Starch and Chemical Company under the product designation "ECCOBOND 3193-17" is applied to a portion of the container where the module **250** is to be located. The module **250** is then mounted to the container portion.

Next, the heater chip module **250** and the container **22** are heated in an oven at a temperature and for a time period sufficient to effect the curing of the adhesive that joins the heater chip module **250** to the container **22**.

A portion of the flexible circuit **190** which is not joined to the spacer **156** is bonded to the container **22** by, for example, a conventional free-standing pressure sensitive adhesive film.

It is also contemplated that the flexible circuit **190** may be coupled to the bond pads **168** on the heater chip **160** after the nozzle plate/heater chip assembly is secured to the support substrate/spacer assembly.

It is further contemplated that the nozzle plate **70, 170** may be coupled to the heater chip **60, 160** after the heater chip **60, 160** is bonded to the support substrate **54, 154**.

Because a substantial portion **58** of the support substrate **54, 154** is formed from a material having substantially the same coefficient of thermal expansion as the heater chip is base **64, 164**, the heater chip base **64, 164** and the support substrate **54, 154** expand and contract at essentially the same rate. This is advantageous for a number of reasons. First, it is less likely that bonding material joining the heater chip to the carrier will fail. Further, if two or more heater chips are secured to the carrier, accuracy of dot placement is increased as the location of the heater chips relative to the paper is less likely to vary. The support substrate portion **58** is also formed from a material having a thermal conductivity which is substantially the same as the thermal conductivity of the material from which the heater chip base **64, 164** is formed. Hence, the carrier provides a dissipation path for heat generated by the heater chip. Consequently, heat build up in the heater chip, which might occur if the thermal conductivity of the support substrate portion is less than that of the heater chip base, is avoided. The support substrate portion may also be formed from a material having a thermal conductivity which is greater than the thermal conductivity of the material from which the heater chip base is formed.

It is further contemplated that the support substrate may be formed from a commercially available chemical vapor deposition (CVD) diamond wafer. CVD diamond wafer material has a coefficient of thermal expansion which is approximately equal to that of silicon. Further, it has a thermal conductivity which is greater than that of silicon. This material is commercially available from Norton Diamond Film of Northboro, Mass.

What is claimed is:

1. A process for forming an ink jet heater chip module comprising the steps of:

providing a carrier comprising a support substrate, the support substrate having a first outer surface and a second outer surface and having at least one passage extending therethrough from the first outer surface to the second outer surface, at least a portion of said support substrate being formed from silicon;

providing a heater chip having a first surface and a second surface opposite the first surface, the heater chip containing a plurality of heating elements on the second surface thereof;

providing a nozzle plate;

securing said nozzle plate to the second surface of said heater chip; and

securing the first surface of said heater chip to the second outer surface of said support substrate, so that the nozzle plate is on an opposite side of the heater chip from the support substrate.

2. The process for fanning an ink jet heater chip module as set forth in claim **1**, wherein said step of providing a carrier including a support substrate having at least one passage extending therethrough comprises the steps of:

providing a silicon plate having first and second outer surfaces;

forming a first etch resistant material layer on said silicon plate first outer surface, said first layer including at least one opening extending through said first layer; and

forming a second etch resistant material layer on said silicon plate second outer surface.

3. The process for forming an ink jet heater chip module as set forth in claim **2**, wherein said step of providing a carrier including a support substrate having at least on passage extending therethrough further comprises the step of forming at least one passage through said silicon plate which communicates with said opening in said first layer.

4. The process for forming an ink jet heater chip module as set forth in claim **3**, wherein said step of forming at least one passage through said silicon plate comprises the step of etching through said silicon plate from an exposed portion of said first outer surface of said silicon plate to said second

etch resistant layer such that said passage has a shape which converges inwardly from said first outer surface of said silicon plate to said second outer surface of silicon plate.

5. The process for forming an ink jet heater chip module as set forth in claim **3**, wherein said step of forming at least one passage through said silicon plate comprises the step of etching through said silicon plate from an exposed portion of said first outer surface of said silicon plate using a tetramethyl ammonium hydroxide etching solution.

6. The process for forming an ink jet heater chip module as set forth in claim **3**, wherein said step of forming at least one passage through said silicon plate comprises the step of etching through said silicon plate from an exposed portion of said first outer surface of said silicon plate using a potassium hydroxide etching solution.

7. The process for forming an ink jet heater chip module as sot forth in claim **2**, wherein said step of providing a carrier including a support substrate having at least one passage extending therethrough further comprises the steps of:

forming at least one passage through said silicon plate which communicates with said opening in said first layer; and

forming at least one opening in said second layer which communicates with said at least one passage.

8. The process for forming an ink jet heater chip module as set forth in claim **1**, wherein said step of providing a carrier comprising a support substrate having at least one passage further comprises the steps of:

providing a spacer, and

securing said spacer to the second outer surface of said support substrate, said spacer having an opening defined by inner side wails, a section of said second outer surface of said support substrate and said inner side walls of said spacer defining an inner cavity of said carrier, said heater chip being positioned in said inner cavity and said at least one passage communicating with said inner cavity.

9. The process for forming an ink jet heater chip module as set forth in claim **8**, wherein said step of providing a heater chip comprises the step of providing a center feud heater chip.

10. The process for forming an ink jet heater chip module as set forth in claim **8**, wherein said step of providing a heater chip comprises the step of providing an edge feed heater chip.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,796,019 B2
DATED : September 28, 2004
INVENTOR(S) : Komplin et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

<u>Column 1,</u>
Lines 22 and 23, change "inference" to -- reference --

<u>Column 13,</u>
Line 26, delete "is" after "flexible" and before "circuit"
Line 64, delete "is" after "heater chip" and before "base"

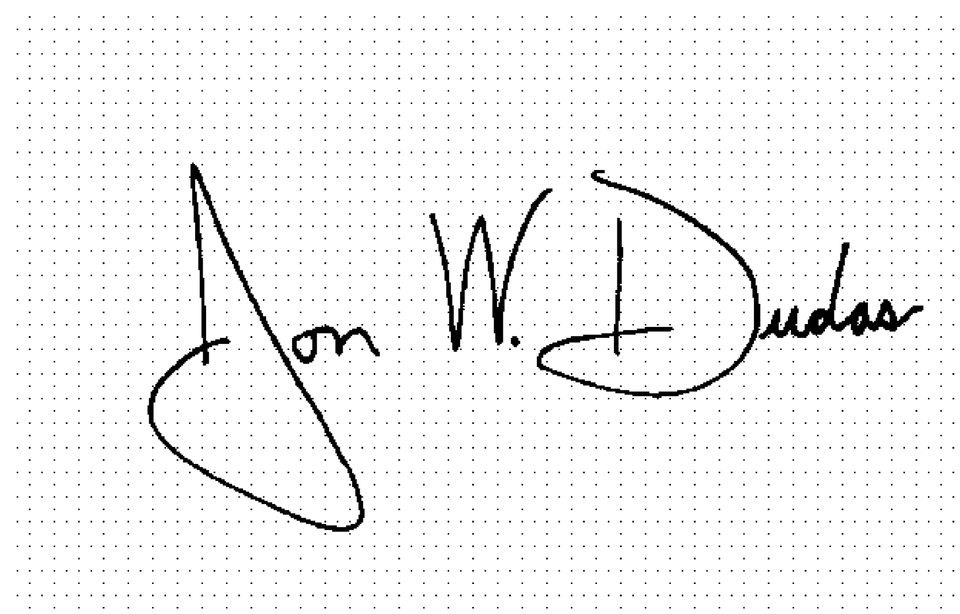
<u>Column 14,</u>
Line 46, change "fanning" to -- forming --
Line 59, change "on" to -- one --

<u>Column 15,</u>
Line 17, change "sot" to -- set --

<u>Column 16,</u>
Line 8, change "wails" to -- walls --
Line 18, change "feud" to -- feed --

Signed and Sealed this

Twenty-sixth Day of April, 2005



JON W. DUDAS
Director of the United States Patent and Trademark Office